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LITTERFALL ASSESSEMENT IN A FRAGMENT OF SECONDARY TROPICAL FOREST, IBIÚNA, SP, SOUTHEASTERN BRAZIL¹

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ABSTRACT – The present study aimed to analyze the production and decomposition of litterfall in a fragment of secondary Atlantic forest in the region of Ibiúna, SP, from April 2012 to March 2013. The litterfall production was estimated by 30 collectors distributed randomly in an area of 1000 m², where the deposited material was collected every 15 days. The decomposition of litterfall was estimated through the mass loss in the period of study. After collecting, the material was dried in an oven at 65 °C for seven days to achieve a constant weight. The decomposition constant k was obtained according to Shanks and Oslen (1961) and the time for 50% and 95% of decomposition was estimated. It was found a higher litterfall production in October (454.3 kg ha⁻¹) and lower production in July (164.9 kg ha⁻¹), with a total amount produced of 3.5 Mg ha⁻¹ year⁻¹. A delay of one month in the precipitation and relative humidity showed great influence in the litter production during the study. The decomposition rate (k) was 3.1 and the time to decompose 50% of the material was estimated in 2 and ½ months and for 95% of the litterfall the time was estimated in 11 and ½ months. The production and decomposition values of this work are within the range found in other sites of secondary tropical forests.

Keywords: Decomposition; Tropical forest; Plant-soil interaction.

AValiação da Serapilheira num Fragmento de Floresta Secundária Tropical, Ibiúna, SP, Sudeste do Brasil

RESUMO – Este estudo teve como objetivo analisar a produção e decomposição de serapilheira em um fragmento de Mata Atlântica secundária na região de Ibiúna, SP, durante abril de 2012 a março de 2013. A produção de serapilheira foi estimada por meio de 30 coletores distribuídos aleatoriamente em uma área de 1.000 m², onde o material depositado foi coletado quinzenalmente. A decomposição da serapilheira foi estimada por meio da perda de massa no período do estudo. Após a coleta, o material foi seco em forno a 65 °C, durante sete dias, para atingir peso constante. A constante de decomposição (k) foi obtida de acordo com Shanks e Oslen (1961), sendo, em seguida, calculado o tempo para decomposição de 50% e 95% do material. Foi encontrada maior produção de serapilheira em outubro (454,3 kg.ha⁻¹) e menor em julho (164,9 kg.ha⁻¹), com uma quantidade total produzida de 3,5 Mg.ha⁻¹.ano⁻¹. A precipitação com atraso de um mês e a umidade relativa do ar mostraram grande influência na produção de serapilheira durante o estudo. A taxa de decomposição (k) foi de 3,1 e o tempo de decomposição, de 50 e 95% do material, estimado em dois meses e meio e 11 meses e meio, respectivamente. Os valores de produção e decomposição deste trabalho estão dentro da faixa encontrada em outros sítios de florestas tropicais secundárias.

Palavras-chave: Decomposição; Floresta tropical; Interação solo-planta.

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1. INTRODUCTION

Litterfall is an extremely important component within the forest ecosystem for nutrient cycling, as well as an indicator of the forest's productive capacity. The knowledge of litterfall amounts in tropical forests is still critical to know and apply biogeochemical models in a climate change scenario (CHAPIN et al., 2002).

Different environments, tree composition, soil type and climate promote different amounts of litterfall production and stock (SANCHEZ et al., 2009; JESUS, et al., 2014), which is determinant for the decomposition rate. All nutrients return occurs primarily through the decomposition which is promoted predominantly by fungi and bacteria, as well as some groups of arthropods. Among the various features of the climate, low temperatures and drought reduce the metabolism of decomposers organism, making their activities reduced (BARBOSA et al., 2010).

It is important to highlight that through the mechanisms of nutrient transference between vegetation and soil some processes of great importance occur for the forest sustainability, where plants drop and uptake resources for growing, once tropical forest soils are normally poor and with low nutrient quality (SILVA et al., 2009) in particular, the Atlantic forest, focus of the present study. The amount of litterfall and its nutrients that are released to the ground by trees will reflect its productive capacity and its potential for environmental recovery, once it is possible to consider that changes will occur in the physical characteristics of the soil (COSTA et al., 2010). Along with the other forest compartments, litterfall contributes to the interception of rainwater through the damping and dispersal of droplet kinetic energy, minimizing the effects of erosion. Tropical forests present an exuberant tree, shrubs and palm flora that depend on the balance of the nutrient cycling (PINTO et al., 2009), which highlights the importance of the decomposition in the system.

The Atlantic forest is fragmented throughout its extension due to an intense history of deforestation and human settlements (LÔBO et al., 2011; LAPOLA et al., 2014). Currently, there are about 8% of the original size of the forest, whereas if secondary forest areas are included, this value rises to approximately 17% (RIBEIRO et al., 2009). Many areas have been reforested and other restored, however, little is known about the

functioning of these forest types in the Southeast region of the Brazil. Secondary forests may exhibit peculiar characteristics regarding the return of nutrients via litterfall, fact which stands out even more the need to know the functioning of this tropical ecosystem, and even more in areas with important role in the connection of natural landscape.

Considering the region of Ibiúna city is between a preserved area of the Atlantic forest and one of the largest cities in the world, São Paulo, and the region presents some small fragments with important ecological meaning, this study intend to respond the following questions: i) what is the litterfall production in this site of secondary Atlantic forest? ii) what are the most important climatic variables that influence such production? iii) what is the decomposition rate in this forest fragment? Thus, the objective of this study was to evaluate the profile of litterfall production and decomposition in a secondary Atlantic forest fragment, in Ibiúna, SP, and to check the main environmental factors (meteorological) that most influence these biotic variables.

2. MATERIAL AND METHODS

2.1. Study Area

The study area is located at Ibiúna, just after the end of the metropolitan region of São Paulo (23°39'20 "S and 47°13'31" W). The average elevation at the site is 996 meters a.s.l., with mean air annual temperature about 19 °C, and high relative humidity, oscillating between 60% and 90%. Located in the physiographic basin of Paranaíacaba, it has a very irregular topography.

2.2. Litterfall production

Litterfall was determined using 30 collectors installed randomly in an area of 1000 m² (20 m x 50 m) and about 0.5 meters from the soil (SCHUMACHER et al., 2011). The material was collected fortnightly during one year (ARAGÃO et al., 2009; HORA et al., 2008), from April 2012 to March 2013, dried in an oven at 65 °C (MENEZES et al., 2010), for 7 days or until it reached constant weight. After drying the material, it was weighted in an analytical balance accurate to 0.01 g. The amount of litterfall produced was estimated with the following model, proposed by Menezes et al. (2010):

$$LP = \Sigma(MP \times 10,000)/ca$$

where: LP = litterfall production ($\text{kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$); MP: monthly production of litter ($\text{kg} \cdot \text{ha}^{-1}$) and ca = collector area (m^2).

2.3. Decomposition of Litterfall

After the remaining mass calculation throughout the period, the decomposition constant (k) was obtained according to Shanks and Oslen (1961), with the exponential model: $k = \text{APL}/\text{AAL}$, where: k = constant of decomposition; APL = annual production of litterfall and AAL = annual average of accumulated litterfall on the ground. This equation has been used in similar studies (VITAL et al., 2004; CIANCIARUSO et al., 2006; PINTO et al., 2009). The decomposition of 50% ($t_{0.5}$) and 95% ($t_{0.95}$) of the material was calculated according to Menezes et al., (2010) following the equation: $T_{0.5} = \ln(2)/k$ and $T_{0.95} = 3/k$, where: k is the constant of decomposition calculated by the previous equation.

2.4. Statistical Analysis

Principal component analysis (PCA) was performed to check possible colinearities between the environment variables. Afterward, correlation and multiple regression were made to find out which of the environment factors better explained the input of litterfall on the forest floor.

3. RESULTS

The climatic variable that presented the highest oscillation along the experiment was precipitation, with the smallest value verified in September (22.5 mm) and the highest in December (268.1 mm). Air temperature remained an average of 19 °C and the relative humidity and solar radiation and wind speed do not present such variations (Table 1).

Principal component analysis (PCA) explained 81% of the variability of the data, with 45,3% of the explanation on the axis 1 and 34,8% on the axis 2. In general, the analysis showed a higher correlation between the values of potential evapotranspiration, precipitation and water excess with the sample units from the months of December, January, February and March and highest values of global radiation, wind speed and temperature with sample units relative to November and October. The water deficit was more correlated with sample units relative to August and September.

The total production of litterfall in Ibiúna, during the period from April 2012 to March 2013 was estimated

at 3,472.1 $\text{kg ha}^{-1} \text{ year}^{-1}$ (Figure 4). The deposition of this biomass reached its maximum value of 454,3 kg ha^{-1} in October 2012, being the smallest value obtained in January 2013, with 164.9 kg ha^{-1} .

The litterfall production throughout the year showed no significant correlation with mean air temperature ($r = 0.343$, $p = 0.275$) and precipitation ($r = -0.06$, $p = 0.840$), but presented significantly negative correlation with relative humidity ($r = -0.57$, $p = 0.05$). The wind speed and solar radiation also showed no significant correlation ($r = 0.414$, $p = 0.181$; $r = 0.196$, $p = 0.541$, respectively) (Figure 5). In relation to the water storage it was observed a significant negative correlation with litterfall production ($r = -0.864$, $p = 0.0002$), a fact not observed for real evapotranspiration and water deficit. However, analyzing the correlation of litterfall produced in the current month in response to the rainfall of the previous month we found a strong negative correlation, suggesting that the response of litterfall presented a delay of one month in relation to the rainfall regime in Ibiúna ($r = -0.741$, $p = 0.009$).

Multiple regression showed that water variables were the most important factor that influenced litterfall production ($p = 0.02$), with emphasis to relative humidity ($p = 0.05$), precipitation ($p = 0.039$) and water storage in the soil ($p = 0.047$), as shown in the equation below:

$$\text{LITTERFALL} = -10.623 * (\text{RH}) + 2.156 * (\text{PREC}) - 0.487 * (\text{WS})$$

The litterfall decomposition constant (k) was 3.1. The time to 50% decomposition of the material ($T_{0.5}$) was approximately 2 and a half months (2.58) and 95% of the material ($T_{0.95}$) was approximately 11 and a half months (11.28).

Some authors have reported different k values of those found in this study, which can highlight the diversity of ecosystems in the tropics, however, the results found in this work are within the expected for tropical secondary forest.

4. DISCUSSION

This profile of meteorological variables in this study follows a typical pattern for the Southeast region of Brazil, especially for terrestrial ecosystem of the Atlantic forest. It is worth noting that real evapotranspiration, as well as other variables related to the water issues, presents great relevance to local

Table 1 – Meteorological variables during the study period. T - average temperature in °C; RH - relative humidity in %; PREC - precipitation in mm; GR - Global Radiation in $\text{kw m}^{-2} \text{day}^{-1}$; WSP – average wind speed in m/s; WS - water storage in mm; EVT - Real Evapotranspiration in mm; WD – water deficit in mm; and WE - water excess in mm.

Tabela 1 – Variáveis meteorológicas durante o período de estudo. T - temperatura média em °C; RH - umidade relativa do ar em %; PREC - precipitação em mm; GR - Radiação Global em $\text{kW m}^{-2} \text{dia}^{-1}$; WSP - velocidade média de vento em m/s; WS - armazenamento de água em mm; EVT - evapotranspiração real em mm; WD - déficit hídrico em mm; e WE - excesso hídrico em mm.

	T	RH	PREC	GR	WSP	WS	EVT	WD	WE
apr/12	22,4	75,8	95,3	3,6	0,9	246,0	69,0	15,0	0,0
may/12	18,8	76,1	90,6	3,2	0,8	427,0	56,0	1,0	0,0
jun/12	18,4	83,5	205,0	2,9	0,5	478,0	46,0	2,0	142,0
jul/12	17,2	75,7	64,4	3,2	0,8	461,0	46,0	2,0	15,0
aug/12	19,6	66,5	0,0	3,7	0,7	293,0	41,0	25,0	0,0
sep/12	21,2	65,2	22,5	3,8	1,1	107,0	17,0	70,0	0,0
oct/12	23,8	66,1	106,7	4,0	1,0	85,0	86,0	26,0	0,0
nov/12	22,6	69,8	57,9	5,0	1,2	96,0	63,0	38,0	0,0
dec/12	25,5	74,2	274,3	4,5	1,0	384,0	147,0	0,0	71,0
jan/13	23,0	78,4	175,1	4,5	1,1	471,0	118,0	1,0	62,0
feb/13	24,3	73,8	105,4	5,0	0,8	440,0	120,0	9,0	15,0
mar/13	23,7	69,2	130,1	4,1	1,1	458,0	102,0	4,0	47,0

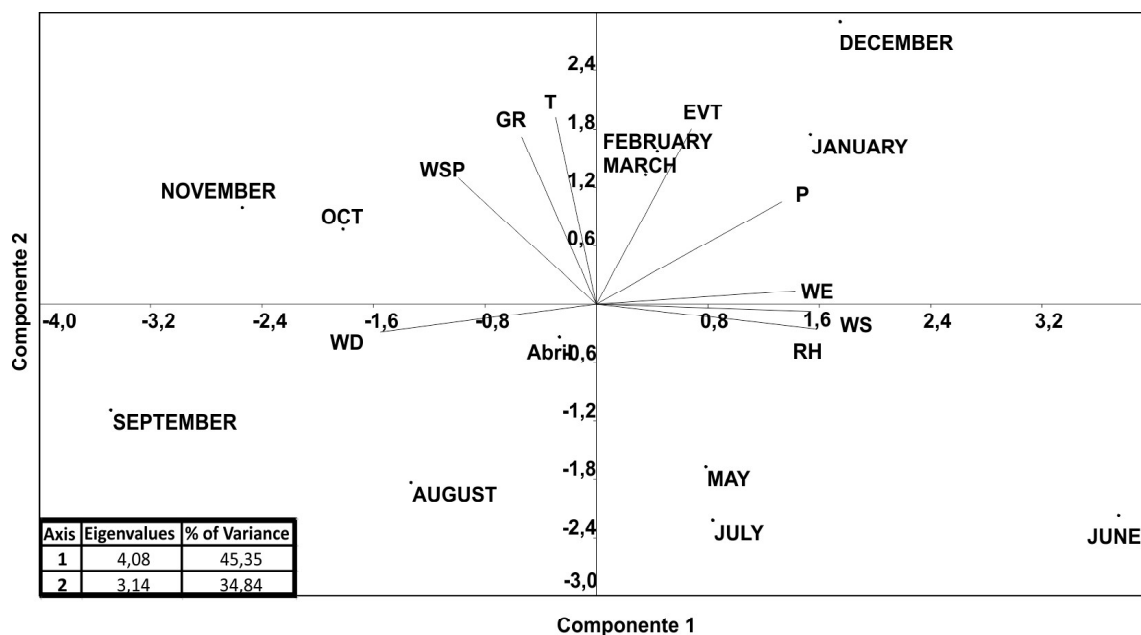


Figure 1 – Main components analysis of meteorological variables in the study area throughout the year. T - average temperature in °C; RH - relative humidity in %; P - precipitation in mm; GR - Global Radiation in $\text{kw m}^{-2} \text{day}^{-1}$; WSP – average wind speed in m/s; WS - water storage in mm; EVT - Real Evapotranspiration in mm; WD – water deficit in mm; and WE - water excess in mm.

Figura 1 – Análise de componentes principais das variáveis meteorológicas na área de estudo durante o ano. T - temperatura média em °C; RH - umidade relativa do ar em %; P - precipitação em mm; GR - Radiação Global em $\text{kW m}^{-2} \text{dia}^{-1}$; WSP - velocidade média de vento em m/s; WS - armazenamento de água em mm; EVT - evapotranspiração real em mm; WD - déficit hídrico em mm; e WE - excesso hídrico em mm.

plant community dynamics, since water is a physical attribute of the environment with great importance in physiological and ecosystem processes (Table 1).

According to Figure 1, the trend of increased litterfall production from September can be explained by the

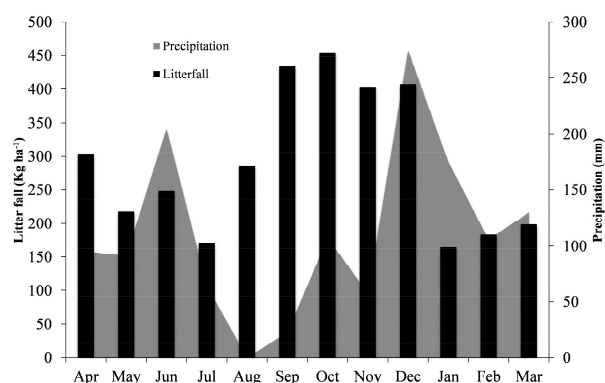


Figure 2 – Monthly average of litterfall production over one year (kg ha^{-1}).

Figura 2 – Média mensal da produção de serapilheira ao longo de um ano (kg ha^{-1}).

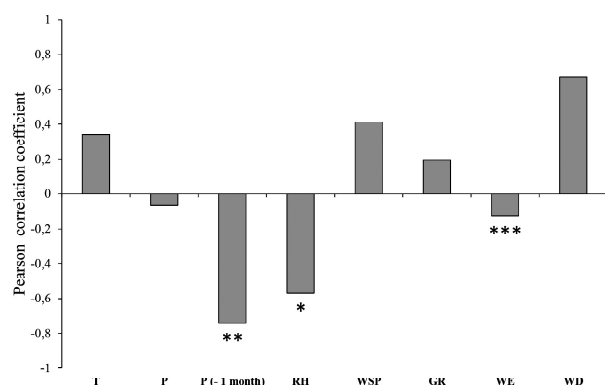


Figure 3 – Pearson correlation factor and meteorological variables. T - mean temperature; P - accumulated precipitation; P (-1 month) - precipitation values for the previous month; RH - relative humidity; WSP - average wind speed; GR - Global Radiation; WE - water excess; and WD - water deficit. Levels of statistical significance: * ($P \leq 0.05$); ** ($P < 0.01$); *** ($P < 0.0001$).

Figura 3 – Fator de correlação de Pearson e variáveis meteorológicas. T - temperatura média; P - precipitação acumulada; P (-1 mês) - valores de precipitação do mês anterior; RH - umidade relativa do ar; WSP - média de velocidade do vento; GR - radiação global; WE - excesso hídrico; e WD - déficit hídrico. Níveis de significância estatística: * ($P \leq 0,05$); ** ($P < 0,01$); *** ($P < 0,0001$).

approaching of the spring season, a fact which could indicate a renewal of leaves and a possible hormonal response to water stress regarding the end of winter for part of the plant community (PAULA et al., 2009), once plants act according to environmental conditions (FERREIRA; DOMINGOS, 2012). Some authors have reported this same trend in tropical forests, such as Menezes et al. (2010) who studied the contribution of litterfall in three distinct characteristics of secondary forests in the Atlantic domain, near the region of Rio de Janeiro and found annual litterfall production ranging from 6,584 to 10,097 $\text{kg ha}^{-1} \text{ year}^{-1}$. Pinto et al. (2009) studied the litterfall in two forests with distinct successional features and found a greater production of deciduous material at the end of the dry season and beginning of the rainy season, being the disturbed place the site with the highest value of litterfall production. Pimenta et al. (2011) studied nutrient cycling in a semideciduous forest in southern Brazil and found a greater production of litterfall at the onset of the rainy season. The authors reported a production of about 5341 $\text{kg ha}^{-1} \text{ year}^{-1}$, being this value close to that found for tropical forests (2-12 $\text{Mg ha}^{-1} \text{ year}^{-1}$) and also close to those found in this study.

In a primary Atlantic forest, Souza Neto et al. (2011) evaluated the litterfall along an altitudinal gradient in the region of Ubatuba, northern region of the São Paulo State and found values of 5.5; 7.4 and 8.4 $\text{Mg ha}^{-1} \text{ year}^{-1}$ for altitudes of 100, 400 and 1000 meters, respectively. It is important to highlight that in a disturbed area with high concentration of atmospheric pollution near São Paulo city, Domingos et al. (1997) found values of high litterfall production in September (847 kg ha^{-1}) and lowest in July (337 kg ha^{-1}), with total production estimated of 7007 $\text{kg ha}^{-1} \text{ year}^{-1}$. In another environment, Ferreira et al. (2014a) found 5.4 $\text{Mg ha}^{-1} \text{ year}^{-1}$ in an urban forest of São Paulo and attributed the changing of wet to dry season as a mechanism that most influenced the production of litterfall.

Interestingly, some climatic variables influenced the litterfall production in this study. Relative humidity and the delay of a month in the rainfall showed inverse and significant relationship with litterfall and this can be explained by the characteristics of the plant community in maintaining the leaves on the trees in response to water availability, since the situation of less water could have stimulated a sign of defense against energy output, such as respiration, being more efficient release higher

Table 2 – Table with decomposition constant values, time for decomposition of 50% and 95% of the litterfall in the literature.
Tabela 2 – Tabela com valores de constantes de decomposição, tempo para decomposição de 50% e 95% da serapilheira na literatura.

Author(s)	Biome	<i>k</i>	Time 50% (month)	Time 95% (month)
This study	Atlantic forest	3.1	2,58	11.28
Fernandes et al. 2006	Atlantic forest	0.00194*	11.9	22.61
Ferreira et al. 2014	Atlantic forest	0,0027*	8,2	35,16
Paula et al., 2009	Atlantic forest	0.0032*	7.2	13.68
Menezes et al. 2010	Atlantic forest	0.0038*	6.06	11.51
Pinto et al. 2009	Atlantic forest	1.36	9	17.1
Lopes et al. 2009	Caatinga	0.71	0.98	4.23
Arato et al. 2003	Cerrado	0.56	1.18	2.24
Cianciaruso et al. 2006	Cerrado	0.56	1.8	3.42

*values in $\text{g g}^{-1} \text{day}^{-1}$ (*valores em $\text{g g}^{-1} \text{day}^{-1}$).

amounts of leaves between September and December. These climatic variables are particularly important for trees ecophysiology, once they also regulate gases changings between plant and atmosphere and thus physiologic process into de plants. Menezes et al. (2010) also found a negative correlation between litterfall production and relative humidity, however, the authors found a positive correlation between the deciduous material and rainfall precipitation. For these authors, the long period with low temperatures and low winter rainfall regimes reflect a high fall of leaves early in the season of spring, when it starts to rain in the region and temperatures increase.

The months of January, February and March of 2013 presented opposite trend of litterfall production and solar radiation, a fact that reinforces the optimization of plants in the photosynthetic process. The temperature did not provide relevant importance in the production of deciduous material in this study. Giacomo et al. (2012) also found no significant correlations with temperature in a study in deciduous tropical Forest, in the region of Minas Gerais. Thus, it is possible that this community responded more efficiently to local water conditions, showing that soil water deficit might trigger a defense mechanism of trees against a possible situation of water stress, thus promoting the fall of leaves as a strategy of economy in the use of water, even if this costs a smaller carbon assimilation through photosynthesis. This might also be a response triggered by hormonal mechanisms (PEZZATTO; WISNIEWSKI, 2006), in which the sensitivity by the lack of water in the soil may trigger physiological, morphological and structural changes. Other papers also reported this water-saving

strategy for plant community, as reported in the work de Menezes et al. (2010) and Sanches et al. (2009).

The decomposition rate in this study was quite high for tropical forests, but it is important to highlight that this is a secondary forest with some regeneration characteristics. Golley et al. (1978) found that in tropical forests, the values of *k* are usually greater than 1. Souza Neto et al. (2011) found subtly similar values in a site of the Atlantic forest located in the northern coast of São Paulo State, being for the altitudes of 100, 400 and 1000 meters the *k* values of 2; 1.4 and 1.3, respectively. For 50% of litterfall decomposition the authors found 3, 5 and 5 months respectively. It is noteworthy that these authors worked in a primary forest and these kinds of environment tend to have slower decomposition rates due to the characteristics of greater system stability. Some others important factors not measured in this work influence the decomposition rate such as the decomposers composition and the soil quality. Ibiúna is in a watershed with accidented topography and poor nutritional soil characteristics, which might contribute for a particular and important environment.

The difference in decomposition rates among rainforests can be attributed to the quality of the material, the type of vegetation covering, fauna activity in the soil and environmental conditions, especially temperature and humidity (ARATO et al., 2003). Ferreira et al. (2014b) found values of nutrient devolution from litterfall to soil in a forest of São Paulo similar to other forests in the Atlantic domain, even the study was carried out in an urban environment, which indicates that the atmospheric pollution of São Paulo could not influence the quality of Ibiúna's forests due to its proximity. Studying

Cerradão, a biome in Brazil, Cianciaruso et al. (2006) presented $k = 0.56$ and the decomposition time of 50% of material estimated for 1.8 years. Menezes et al. (2010) found half life time of 182 days across forests with different successional states in Pinheiral, RJ. Table 2 demonstrates some studies carried out in tropical forests and their respective k values, time of decomposition of 50 and 95% of the litterfall.

5. CONCLUSIONS

This study showed a profile of litterfall production within a year in a secondary forest of the southeastern region of Brazil, with greater value produced at the beginning of the rainy season. The most important weather variables that influenced such production were related to water issues such as water storage, relative humidity and precipitation. The decomposition rate of litterfall was relatively high and within the expected for secondary forest in tropical sites, once some authors have reported similar values for forests in the State of São Paulo.

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